CORRECTED TOTAL REFLECTION REFLECTORS FOR SOLAR RADIATION CONCENTRATION SYSTEMS WITH LARGE CONCENTRATION RATIOS AND CORRECTED WAVE GUIDES WITH LOW TRANSMISSION LOSSES

BACKGROUND

Construction of Concentrating Photovoltaic (P/V) Systems with conventional parabolic reflectors or with parabolic total reflection reflectors is a well known technology. Yet, current concentrating P/V systems in the market are not cheaper than the conventional, and generally expensive, flat P/V systems. The reason for such market condition is that the construction of parabolic Total Reflection Reflectors (TRRs) from common transparent glass, which would be the cheapest and the most resilient solution, often faces construction difficulties which prevent accomplishing large concentrating ratios.

The main of such difficulties is that the parabolic TRRs from glass have, due to their construction and related technical aspects, rear rectangular prisms with larger height and width than the ones made out of acrylic (compare, for example, the 2-10 mm sizes of those TRRs made of glass with the 0,02-0,2mm of the acrylic ones). In addition, rectangular prisms present diffusion and poor focusing of the solar rays, which typically gets worse exponentially as their height and their width increase, and thus limits drastically the concentration ratios.

Moreover, such optical imperfection limits the use of secondary reflectors employed for the reduction of the solar image size and the achievement of a Narrow Secondary Beam and high level of concentration ratios, which would be necessary for supplying solar radiation to hollow Solar Wave Guides (Solar Arteries) for the injection of such solar radiation into buildings in order to employ it for solar lighting. The same optical imperfection also limits the construction of hollow Solar Wave Guides (Solar Arteries) with small losses for the transfer of the Solar Radiation inside the buildings for the replacement of artificial lightning with solar lighting.

Until today there have been efforts to transfer solar radiation inside buildings by using large diameter fiber optics. Such approach, even for the most clear fiber optic materials, presents great losses for the solar spectrum (e.g., 50% losses for propagation distance of 20-30 meter).

SUMMARY

The present disclosure relates to the development of total reflection reflectors for the construction of various solar concentrators or other type of concentrating systems with large concentrating ratios for simultaneous production of electrical power and thermal power. The various solar concentrators include concentrative Total Reflection Reflectors with Curved Rectangular Total Reflection Prisms; the TRR disclosed herein do not present the optical imperfection of diffusion and poor focusing of solar rays, in contrast to conventional TRR with rectangular total reflection prisms.

The correction of this optical imperfection can allow the construction of Parabolic TRR made of common transparent glass with large dimensions (height and width ranging from 2-10 mm or larger) of the rectangular prisms of the Parabolic TRR, as it is technically necessary for the glass-based technology, while simultaneously allowing the possibility of excellent focusing with large (real) concentrating ratios (500 or 1000 suns or even more). In addition, the correction of such optical imperfection can made possible the use of Secondary Parabolic or Ellipsoidal Total Reflection Reflectors for the shrinkage of the solar image's size and the achievement of even larger (real) concentrate ratios (over 1500 suns) as well as the creation of the Narrow Secondary Beam of Rays with beam-angles sized from 5^0-10^0 for the injection of the solar radiation into Solar Wave guides for transferring the solar radiation inside buildings for solar lighting therein. Moreover, correction of such optical imperfection allows the construction of Solar Wave Guides with minimum losses for efficient transmission of the solar radiation to sufficiently long distances with an acceptable loss-level (e.g., acceptable losses for internal lighting of buildings with solar light).

BRIEF DESCRIPTION OF THE DRAWINGS

Drawing 1a presents a full parabolic Total Reflection Reflector.

Drawing 1b presents a detail (Detail A) of Drawing 1a related to the formulation of the Curved Rectangular Prisms for the correction of the diffusion imperfection of the conventional Parabolic Total Reflection Reflectors; the diffusion imperfection due to the simple Rectangular Prisms.

In Drawing 1c, the typical construction of a hollow Solar Wave-guide with total reflection walls (Solar Artery) is presented.

Drawing 1d presents a detail (Detail A') which shows the implementation of the Curved Rectangular Prisms, which removes the diffusion imperfection of the conventional Solar Artery; the diffusion imperfection related to simple conventional Rectangular Prisms.

Drawing 2 presents a Solar Concentrator System S/S (100_A) that concentrates solar energy and transforms it into a Narrow Beam for the production of electrical and thermal energy or the injection into hollow Solar Wave-guides (Solar Arteries).

Drawing 3a presents a Solar Concentrator System S/S (500_A) where a Solar Artery is also used to transfer solar energy into the building for solar lighting.

Drawings 3b and 3c present an Angular Accessory (571_A) and Multiple Angular Accessory (581_A) for supplying solar radiation into Solar Arteries.

DETAILED DESCRIPTION

Below is given the detailed technical description of the Solar Concentrator Systems S/S 500_A, 100_A, 600_A, equipped with the novel corrected parabolic Total Reflection Reflectors (TRR) 001_A with corrected Hollow Rectangular Prisms (HRP) 007_A or $007'_A$ and with the novel Solar Arteries 551_A with corrected Hollow Rectangular Prisms 556_A or $556'_A$ for the removal of the optical imperfections diffusion and bad focusing typically present in the conventional parabolic TRR and Solar Arteries (because of the simple Rectangular Prisms), and the achievement of high solar radiation concentration.

1. Solar Concentrator System of Single Point Focusing S/S (500_A) for Solar Lighting, Air-Conditioning and Water-Heating in Buildings

The Solar Concentrator System S/S 500_A, which is shown in the Drawings 1a, 1b, 1c, 1d, 2 and 3a, 3b, 3c, is characterized by the fact that it is equipped with corrected Primary Parabolic Total Reflection Reflector 501_A and Secondary Ellipsoidal Reflector 201_A as well as the corrected Solar Arteries 551_A and the Accessories of the Arteries 571_A and 581_A, which are all equipped with Curved Rectangular Prisms (CRP) 007_A, CRP $007'_A$ and 556_A correspondingly, as all these are shown in the Drawings 1a, 1b, 1c and 1d, and as they are described in Sections 4 and 5 below. The Solar Concentrator System S/S 500_A removes optical imperfections (e.g., diffusion and poor focusing) of simple, conventional rectangular total reflection prisms.

The Solar Concentrator System S/S 500_A also is characterized also by the fact that it is designed for the supply of Solar Lighting in a building and the simultaneous production of cooling and thermal energy.

Construction of the Structural Elements of the Solar Concentrator System S/S 500_A also characterizes it. Such construction is effected as it is described below:

The primary Parabolic Total Reflection Reflector (PTRR) 501_A (which also is referred to as 101a) consists of a full parabolic reflector or an extract of any form of the full reflector. The primary PTRR 501_A can consist of for example 1,2,3,4 or even more Tiles of Total Reflection (TTR) 131_A based on an appropriate parabolic substrate, each one of the TTRs with main dimensions of about 20 cm by about 20cm (e.g., 20cmx20 cm) so that the (TRR) 131_A can be produced at a low cost by existing automated glass-impression machines. The material of the PTRR 501_A and TTR 131_A consists, e.g., of transparent glass without iron oxide or of transparent plastic self-supporting or supported on an appropriate substrate (as it is shown in the Drawings 2 and 3a).

The Front Surface 113_A, of the TRR 131_A has a smooth parabolic form, while the Rear-Surface (113_Γ) is also parabolic and bas-relief and consists of Corrected Rectangular Prisms 007_A (which also are referred to as 114_A), of which the Top Acmes 115_A converge and meet at the Top 102_A of the full Parabolic Total Reflection Reflector 101_A, which coincides here with the primary PTRR 501_A. The cross-sections of the sides of the Corrected Rectangular Prisms CRP 114_A or 007_A are not straight lines but are the corrected curves of the CRP 114_A or 007_A so that an accurate focusing is achieved.

The S/S 500_A has a Symmetry Axis 551_A, which points to the sun, and the Rotation Axes 512_A and 512_Γ, which are horizontal and vertical axes, respectively. The primary PTRR 501_A is based on a metallic Supporting Frame 505_A (e.g., structured as the parabolic plate of a satellite television antenna made of pressed aluminum sheet). The Supporting Frame 505_A is based on the Vertical Rotation Mechanism 508_A, which is based on the Horizontal Rotation Mechanism 508_B (analogous with the mechanisms 108_A and 109_A described below). Two Bearings 508_Γ enable the Supporting Fram 505A to be based on the Supporting Base 510_B.

The Secondary Total Reflection Reflector (STRR) 201_A consists of a full paraboloidal or ellipsoidal reflector depending on whether the STRR 201_A is placed in front of or behind the Focus 504_A or 104_A. In the illustrated embodiment, the STRR 201_A is placed behind the Focus

504_A and it is ellipsoidal. In the alternative, the STRR 201_A can be an extract of any shape [analogous of the corresponding (501_A)]. The STRR 201_A is made of the same material as the corresponding 501_A. The STRR 201_A can also consist of, e.g., 1,2,3,4 or even more Total Reflection Tiles (TRT) 231_A, as illustrated in Drawings 2 and 3, and which are based on the metallic Supporting Frame 507_A which is based on the Supporting Frame 505_A.

The Front Surface 213_A of the TRT 231_A has a smooth ellipsoidal (or ellipsoid of revolution) form while the Rear Surface 213_Γ is also ellipsoidal and bas-relief and consists of Corrected Rectangular Prisms 214_A. The Acmes 215_A of the CRP 214_A converge to the Top (202_A) of the (201_A), while the cross-sections of the Sides (233_C) of the Corrected Rectangular Prisms (CRP) 214_A are not straight-lines but they are the corrected curves of the CRP so that accurate focusing is accomplished.

The primary Total Reflection Reflector 501_A (corrected with CRP 007_A) creates the Wide Beam of Rays 052_A, which impinges onto and is reflected backwards by the Secondary Reflector 201_A, which in the illustrated embodiment is designed ellipsoidal (or of ellipsoid-of-revolution shape) in appropriate size and is placed behind of the Focus 504_A, so that it reduces the solar image to a desirable level, and creates the Narrow Beam of Rays $053_A$with a desirable beam angle (e.g. smaller than $\pm$ 5°).

Solar Concentrator System S/S 500_A also possesses a Reflection Medium (231_Γ) of the Narrow Beam of Rays 053_A before it focuses on the Focus $504'_B$ (e.g. a Total Reflection Reflector with parallel rear surface total reflection prisms) placed at a 45° angle towards the Narrow Beam Axis 053_A, close and behind the Focus $504'_B$ and close to the Entrance of the Solar Artery 551_A, so that the Reflection Medium 231_Γ reflects the Narrow Beam 053_A into the Solar Artery 551_A, which is placed with its opening close to the Focus 504_A of the reflected Narrow Beam 053_A and its Axis 553_A, which is parallel to the axis of 053_A. In those occasions or during that time of the day when the Solar Lighting is not needed inside a building, the TRR 231_Γ, or other installed TRRs, may be removed, and thus the Narrow Beam can focus directly onto a selective black absorbent surface 562_A which is placed on the Focus $504'_B$ which can transfer the heat of the Beam 053_A into the Working Fluid 502_E, which can be utilized as hot water or as cooling power used for air-conditioning through the Adsorption Heat Pump 519_A with Silicagel, etc].

Alternatively, the Reflection Medium 231_Γ may be a Cold Mirror 231_Γ at a 45° angle towards the Narrow Beam Axis 053_A, and need not be close to the Focus $504'_B$ or close to the Solar Artery 551_A. Cold mirror 231_Γ can only reflect the visible part of the solar radiation spectrum (from λ=0,4 until λ=0,7μm) with a coefficient of reflectivity above 96%, at an angle of 90° towards the Solar Artery 551_A (which is placed with its Opening at the Focus 504_A of the Narrow Beam 053_A and its Axis 553_A parallel to the axis of 053_A), while Cold Mirror 231_Γ will allow the infrared (IR) part of the spectrum (from λ=0,7 to λ=2,4μm) to get through it with few absorption losses of the order of 5-10%. The IR part of the Narrow Beam 053_A will focus straight onto a selective black Absorbing Surface 562_A placed at the Focus ($504'_A$), which will transfer the heat of the IR Beam 053_A to the Working Fluid 502_E (which will be utilized as hot water or as cooling power used for air-conditioning through the Adsorption Heat Pump 519_A with silicagel, etc.) avoiding at the same time transferring the heat of the IR part of the solar radiation spectrum into the building, saving in that way the corresponding power of the chiller of the air-conditioning units of the building.

The reflected Narrow Beam of Rays 053_A will be focused on the Center (552_A) of the Solar Artery (551_A), which is placed close to the final Focus (504_B) with the Axis (553_A) of the Solar Artery parallel to the Narrow Beam Axis (053_A). The Solar Artery (551_A) is constructed as described below in Section 5. Subsequently, the Narrow Beam 053_A of the total or just of the visible part of the solar radiation spectrum, through the Solar Arteries 551_A is transferred to the interior of the building so that it is used for natural lighting through special Solar Lighting Fixtures (SLF) 591_A.

For one or many primary Reflectors 501_A concentrating the Solar Radiation, which have been arranged on a fixed basis or on a rotating basis, which floats, the Solar Arteries 551_A of each Basic Reflector 501_A are gathered through Angled Accessories 571_A to the Main Multiple Angled Accessory 581_A with which each Solar Beam 053_A of the Solar Arteries 551_A of each Basic Reflector 501_A are inserted into the Main Artery $551'_A$ and transferred to the interior of the building where the Solar Radiation (053_A) is distributed in reverse way to each floor by Multiple Angled Accessories 581_A to smaller Arteries that transmit the light to the rooms intended to be illuminated and wherein the final distribution to lighting fixtures is effected either by Solar Arteries 551_A of small diameter or by optical fibers of large diameter.

For the achievement of constant level of lighting into the rooms, when the intensity of the available solar radiation changes, there will be conventional fluorescent lamps which through a dimmer will keep the lighting level constant, increasing or decreasing correspondingly the lighting flux of the fluorescent lamps.

A first approximation of the energy production or the energy substitution resulting from the Solar Concentrator System S/S 500_A in the case of using the Cold Mirror 231_Γ is the following:

Each KW of incoming solar radiation corresponding to solar radiation received at an Ideal Solar Location (ISL) with 0% diffuse radiation and 100% straight radiation at noon with clear sky and AM1,5, and with an aperture of one square meter of primary Reflector 501_A, when it is split into visible and infrared (IR) radiation, it will provide approximately 500W visible and 500W IR radiation. From the 500W of visible light, using Total Reflection Reflectors and the Solar Arteries described above, approximately 80% of that radiation will be transmitted to the Solar Lighting Fixtures 591_A inside the building. It is known that each W of visible solar light corresponds to 200 lm (compared with approximately 60 lm/W for the state of the art fluorescent lamps which are used for the internal lighting of the buildings). Accordingly, 400W of transmitted visible light will give 80,000 lm which will substitute 80,000/60 = 1330 W of electrical energy (=33 fluorescent lamps of 40W). Moreover they will substitute another 400W of electrical energy, which would have been required from the air-cooled chillers (with COP=2,3) in order to remove 1330-400=930W_{th} thermal load, which remains behind due to the operation of the 1330 W fluorescent lamps.

On the other hand, the IR radiation that focuses at the Focus (504_B) on the Absorbing Surface (562_A) will have approximately 15% losses due to reflection and absorption at the Cold Mirror 531_Γ and emission from the Selective Absorbing Surface (562_A). Which means that the power of the IR radiation which will be delivered to the Absorbing Surface 562_A will be equal to 500x0,85=425W. The latter power will be transferred by the Heating Pump 519_A (Absorbing or Adsorbing) to the Working Fluid 502_E as above, producing 425W_{th} of hot water during the winter, or it will be transformed into cooling power (as chilled water, with COP 0,7 till 0,9 average 0,8 due to the higher permissible temperatures of hot water) equal to 435x0,8=340 W for air-conditioning units during the summer, thus substituting 340/2,3=150 W of electrical power of the air-cooled chillers, which would have been required by them for the same cooling power.

At the same time, the Silicagel Adsorption Heat-Pump 519_A (which can transform hot water of 60°-90°C into cold water of 7°/12°C for air-conditioning with a COP of 0,7 approximately) will produce in parallel an intermediate stream of lukewarm water of 30°-32°C from the condensation of the water vapor during the adsorption cycle with a thermal power of approximately 425W, appropriate for pool- heating or for warming-up of domestic hot water etc. The total attribution of the IR part of the solar radiation will be 150W of substituted electric energy of air-conditioning plus 425W of lukewarm water during the summer or 425W of hot water during the winter.

Thus, the Solar Concentrator System S/S (500_A) can produce or substitute for each KW of incoming Solar Energy (which corresponds approximately to 1 m^2 of aperture surface of a primary Reflector for an ISL):

-For the part of the Visible Spectrum

- 1330W of substituted electrical energy for building lighting (substitution of 33 fluorescent lamps approximately)
- 400W of substituted electrical energy for air-conditioning

-For the part of I/F Radiation (only hot water and air-condition without P/V):

- 150 W of substituted electrical energy for air-conditioning plus
- 425W for the production of lukewarm water during the summer and
- 425W for the production of hot water during the winter

-Total: 1880W of substituted electrical energy and 425W of lukewarm water during the summer and 1330W of substituted electrical energy plus 425W of hot water during the winter. This means more than 2,30 KWp during the summer and approximately 1,75 KWp during the winter of substituted or produced electrical and thermal energy for each KWp of incoming solar energy.

Compared with conventional P/V Systems, which produce approximately 120 to 180Wp of electric energy for each 1000 Wp of incoming solar energy, the present Solar Concentrator System S/S $500_{A,B}$ produces or substitutes more than 10 times in electrical and 3 times in thermal or cooling power (for hot water or air-conditioning power) in an affordable price, which will allow the amortization of the Solar Concentrator System S/S 500_A in less than 3 years, even without incentives.

2. Solar Concentrator System of Single Point Focus S/S 100_A

The S/S 100_A, which is described herein and shown in the Drawing 2 is characterized by the fact that it includes a full primary Parabolic Reflector of Total (or even simple conventional) Reflection (PRTR) 101_A with Top the point 102_A. In the S/S 100_A, the Solar Rays 051_A, after their incidence on the primary PRTR (101_A), create the first reflected Wide Beam of Rays 052_A, which focus on the Focus 104_A and either they are utilized directly there focusing on the P/V Cells 302_A with the help of the Auxiliary Reflector 363_A or alternatively after they reflect on the Secondary Reflector 201_A (which is supported with the Brackets 207_A on the Ring 105_A), they create the Narrow Beam of Rays 053_A, which reaches the Final Focus 201_A and focuses there on the P/V Cells 302_A with the help of the Auxiliary 363_B as well, which are based on the Ring 105_Γ. The Reflector 101_A is based on the metallic Supporting Rings 105_A (External) and 105_C (Internal), which are supported by the metallic Supporting Brackets 107_A, which are based on the Horizontal Rotating Head 108_A. The Head 108_A is based on the Pillar / Vertical Rotating Mechanism 109_A, which is based on the Base 110_A.

The Total Reflection Reflector 101_A consists, e.g., of transparent water-clear glass without iron oxides (one-piece for small surfaces, or Total Reflection Tiles (TRT) 131_A, which consist part of the Parabolic Surface $113'_A$ for larger surfaces based on an appropriate parabolic substrate) or of transparent plastic self-supporting or based on an appropriate substrate. The Front Surface 113_A of the $113'_A$ has a smooth parabolic form, while the Rear Surface 113_Γ has a bas-relief parabolic form and is parallel with the 113_A and consists of Corrected Curved Rectangular Prisms 114_A or 007_A, of which the Top Acmes 115_A converge and meet at the Top 102_A of the Reflector 101_A. Moreover we have the Symmetry Axis 111_A (which aims to the Sun) and the Rotation Axes 112_A and 112_Γ (Vertical and Horizontal, respectively).

The Secondary Reflector 201_A has a paraboloid or ellipsoid form by rotation (depending on whether it is placed in front or in the back of the corresponding Focus 104_A or 504_A; in the illustrated embodiment, it is designed as an ellipsoid for reducing the solar image) and may consist of 1,2,3,4 or even more Total Reflection Tiles (TRT) 231_A. For TRT 231_A, the Front Surface 231r is smooth ellipsoid, while the Rear Surface (213_Γ) is bas-relief ellipsoid and parallel to the 213_A, and consists of Corrected Curved Rectangular Prisms (CRP) 214_A, of which the Top Acmes 215_A converge and meet at the top 202_A of the Reflector 201_A.

3. The Solar Concentrator System S/S 600_A for Solar Lighting, Solar Air-Conditioning, Solar Water Heating and Electrical Energy from P/V.

The Solar Concentrator System S/S 600_A which is shown in the Drawings 3a, 3b, 3c is constructed like the Solar Concentrator System S/S 500_A, but it is characterized by the fact that it is designed for the production of Electrical Energy on in addition to Solar Lighting and the production of Cooling or Heating power of the S/S 500_A by adding the Structural Elements which are related to P/V (the P/V Cells (302_A), the focus Auxiliary Reflectors (363A), the Cables (340_A) and the batteries or the Inverters) to those ones of the S/S 500_A as mentioned below. All the Structural Elements (S/E) of the S/S 600_A, which are similar to those ones of the S/S 500_A and to those ones of the S/S 100_A, are named with the same names and code numbers as the corresponding of the S/S 500_A and S/S 100_A, but they change the first code number from the 5 or 1 to 6 (for example, the Vertical Rotating Axis 512_A of the S/S 500_A changes to 612_A in the S/S 600_A, while the 302_A, 363_A and 340_A of the S/S 100_A change to 602_A, 663_A and 640_A in the S/S 600_A correspondingly) and are modified correspondingly for the functional form of the S/S 600_A (for example, the Absorbing Surfaces 662_A do not need any more to be covered with selective absorbing radiation layer and the P/V Cells 602_A may be_sensitive to the IR).

For this purpose the P/V Cells IR 602_A, the Cables and the Auxiliary Reflectors 663_A are added on top of the heat Absorbing Surfaces 662_A behind the Cold Reflector 631_r on the Final Focus 604_B, thus exploiting the incident concentrated radiation first for the production of P/V electrical energy and afterwards for the production of hot water as above.

4. Corrected Parabolic and Paraboloid or Ellipsoid Total Reflection Reflectors with Curved Rectangular Prisms.

In the following, a detailed technical description of the construction of the novel parabolic Total Reflection Reflectors (TRR) (001_A) with Curved Rectangular Prisms (CRP) (007_A) for the correction of the optical imperfection of diffusion andpoor focusing of the conventional parabolic TRR (due to the simple rectangular prisms) and the accomplishment of high concentration ratios is provided.

In Drawing 1a, a full parabolic Total Reflection Reflector (001_A) is shown, which is characterized by the fact that it is equipped with the exterior Bas-relief Surface 002_A, which bears Curved Rectangular Prisms (CRP) 007_A as they are shown in the Drawing 1b. In the

Detail A in Drawing 1b, the Rectangular Prism $H_1\Theta H_2=007_A$ is shown, which arises from a section of the External Surface (002_A) with the Plane 013_A normal to the tangential of the Acme 012_A of the (not yet corrected) Rectangular Prism 007_A at the Point Θ. The plane 013_A is normal to the Internal Surface 004_A at the point O_1 and its section with the (004_A) in the area of the Point O_1 is with great approximation a Periphery Π_1 of a circle with a radiant $O_1E=\sqrt{2}xO_1E_0$.

For the sake of simplicity, it is assumed that the Focus E_0 of the (001_A) is located on the section of the Plane 005_A with the Axis 003_A, that the Point K'_1 is located on the Periphery (005_A) and that the Periphery Π_1 =(013_A) has a Diameter Δ_1= 360cm/p = 114,6cm and, consequently, the length of the Periphery $\Pi_1=013_A$ equals with $\frac{360}{\pi}\pi$= 360 cm. Further assuming that the parabolic TRR (001_A) includes 150 Rectangular Prisms (007_A), results that the width of each Rectangular Prism (007_A) corresponds on the Π_1 =(013_A) to an arc with length of 2,4 cm or to an angle φ=2,4°.

It is considered the vector Component AK_1 of the incident Solar Ray 006_A =$A_0K'_{10}$, which coincides with the section K'_1E of the plane that is defined by the incident Solar Ray (006A)=$A_0K^1{}_{10}$ in combination with its parallel Axis 003_A of the (not corrected yet) parabolic TRR 001_A with the Plane 013_A. The Ray $AK'_1=K'_1E$ falls vertical on the Periphery 013_A at the point K'_1 at the area of the (not corrected yet) Rectangular Prism 007_A (where $O_1K'_1$=1,0 cm and (k_1=1°), penetrates at a straight line to the interior of the Rectangular Prism 007_a and falls onto the Side $H_1\Theta$ to the point K_1 under an angle of 44° to the vertical $K_1\Lambda_1$ and is reflected under an angle of 44° and intercepts the Side QH_2 at the point K_2 under an angle of 46° to the Vertical $K_2\Lambda_2$ and is reflected under an angle of 46° to it and emerges from the TRR 001_A at the point K'_2 under an angle of 3° as to the $K'_2\Delta''$ (which is vertical to the Tangent K'_2O_1'' of the Periphery Π_1 =013_A at the Point K'_2). The Vertical $K'_2\Delta''$ comes through the Center E of the Periphery $\Pi_1=013_A$ and is the desirable route of the projection of the emerging Ray $K'_2\Delta$ in order that it focuses at E and consequently the real Ray $K'_{20}\Delta''_0$ focuses at $E_0{}^1$.

Accordingly, it is proved that a conventional Rectangular Total Reflection Prism presents an aberration angle φ_4 (Convergence Aberration) of the emerging vector component Ray $K'_2\Delta$ (after the Total Reflection of the vector component Ray AK'_1 as above) as to the desirable

routing $K'_2\Delta''$ for accurate focusing that is equal to $3\varphi_1$ (where φ_1 is the angle that corresponds to the arc $O_1K'_1$), and the same Convergence Aberration presents the real emerging Ray $K'_{20}\Delta''_0$. It is therefore obvious that due to the existence of the Convergence Aberration ($\varphi_4=3\varphi_1$, in order to have a tolerable Focusing with conventional (not corrected) parabolic TRR, these must be obligatorily of a very small thickness wall, e.g., of colorless plastic (acrylic, etc.) and the height and width of their Rectangular Prisms to be as small as possible so that the Convergence Aberration is as small as possible correspondingly, [because the φ_1 is almost straight proportional with the height 008_A = 1/2 width of 009_A of the corresponding Rectangular Prism 007_A for a given Diameter D= 010_A = 005_A of the Parabolic TRR 001_A].

In contrast in the parabolic TRR made of common water clear glass with n=1,5 and dimensions of height-width of the Rectangular Prism of the order of 2-10 mm as above, if the correction of the Convergence Aberration $\varphi_4=3\varphi_1$ will not be done with Curved Rectangular Prisms 007_A as given below, then the Convergence Aberration for the previous example with Periphery Π_1 = 013_A = 114,6 cm and D= 005_A = $\frac{114{,}6}{\sqrt{2}}$ =81 cm and Height 008_A= 1/2 Width 009_A of the Rectangular Prism in the Periphery Π_1= 013_A equal to 1,2 cm, incidence of the Ray A at a distance O_1K_1=1,0cm from the Point O_1 and Focusing Distance $K'_{20}E_0$= $\frac{114{,}6}{\sqrt{2}}$ = 81 cm, we will have $\varphi_1=1°$ and $\varphi_4=3°$ and an aberration of the Reflected Ray $K'_{20}\Delta_0$ from the Point E_0 of the Focus equal to 81*tan3° = 4,25cm (for Rays A_1 incident to the Point H_1 the aberration grows larger than 5,1 cm). Consequently the theoretical ratio of concentration is limited below 250 (and in the reality due to imperfections of the projection the Solar Image etc even more) with a consequence that such a parabolic TRR is completely inappropriate for P/V Concentrating Systems with concentrating ratios larger than 200 or even less.

---

[1]For this analysis, it has been assumed a diffraction coefficient n=1,5 for common transparent glass and that $\sin\varphi_4/\sin\varphi_3$ = 1,5 = φ_4/φ_3 with a very good approximation due to the very small angles φ_4 and φ_3.

Therefore in order to have an accurate focusing of the Emerging Ray $K'_{20}\Delta''_0$, this and the vector component Ray $K'_2\Delta$ must take the direction of the straight line $K'_2\Delta''$ which is vertical to the tangent K'_2O_1'' at the point K'_2 and therefore passes through the Center of the Periphery $\Pi_1 = 013_A$ so that the real Ray $K'_{20}\Delta''_0$ comes through the Focus E_0 (in the following, and as above, the analysis will be made for the vector components on the plane of $\Pi_1 = 013_A$, which will be valid for the real Rays as well).

This means that the vector component $K'_2\Delta$ of the Ray $K'_{20}\Delta_0$ must be turned counterclockwise (to the left) by an angle of $\varphi_4=3\varphi_1$ and for n=1,5 the vector component $K'K'_2$ of the Ray $K_{20}K'_{20}$ in the Rectangular Glass Prism (007_a) must be turned counterclockwise by an angle of $3\varphi_1/1.5 = 2\varphi_1$ which means that the sides $H_1\Theta$ and ΘH_2 must be turned at the points K_1 and K_2 (the $H_1\Theta$ clockwise (to the right) and the ΘH_2 counterclockwise correspondingly) by an angle of $\varphi_1/2$ each of therm.

At the specific example above, in order to have the revolution of the vector component Ray $K'_2\Delta$ by an angle of 3° (so that it coincides with the vertical $K'_2\Delta''$ and route through the Focus E) the side $H_1\Theta$ must be turned around the point of total reflection K_1 clockwise by 1,0°/2=0,5° (consequently the vector component Ray K_1K_2 will be turned clockwise, according to the clock hands, by 0,5°x2=1,0°) and the side $H_2\Theta$ must be turned around the point of total reflection K_2 counterclockwise by 1,0°/2=0,5° (and consequently the vector component Ray $K_2K'_2$ will be turned counterclockwise, opposite to the clock hands, by 0,5°x2=1 ,0°). Thus, in total, the vector component Ray $K_2K'_2$ will be turned counterclockwise by 1,0° +1,0° =2,0° and the $K_2\Delta$ will be turned counterclockwise by 2,0°x2=3,0° and will coincide with the direction $K_2\Delta''$, which is vertical onto the tangent $K'_2O''_1$ at the point K'_2 (and consequently it will be routed through the Focus E). It is thus proved that in order to focus correctly the reflected rays emerging by total reflection from a parabolic or ellipsoidal or paraboloidal[2] reflector with a rear surface formulated into converging

[2]The analysis is effected on the projections of the Rays 006_A on the plane of the $\Pi = 013_A$. Consequently are valid go what are mentioned also for the case of the paraboloidal or ellipsoidal (TRR) $001'_A$ onto which the incident rays $A'=006'_A$ are not parallel to the Axis $003'_A$ of the $001'_A$ but they originate from a Point $012'_A$ of the Axis $003'_A$ of the Paraboloidal (TRR) $001'_A$.

(at the top of the parabolic or ellipsoidal or paraboloidal reflector) rectangular prisms, then the sides of the rectangular prisms must be rectangular only in a small (dz) area around the top Θ' of each Curved Rectangular Prism 007_A.

At whatsoever other point of them the sides of each rectangular prism must appear, at their projection on a plane vertical to the Acme 012_A of the Parabolic TRR 001_A, an angle of curvature (φ_2 equal with the half of the angle φ_1, where φ_1 is the angle formatted by the tangent of the internal Periphery $\Pi_1=013_A$ at the point K'_1 as above with the tangent of the Periphery $\Pi_1=013_A$ at the Central Point O_1. This means that $\varphi 2 = 1/2\ \varphi_1$ at each point K_1 of the sides of a Curved Rectangular Prism 007_A where the relative each time K_1 corresponds to the each time Points of interception of the incoming vertically (onto the internal Periphery $\Pi_1=013_A$) vector components of the Rays A_o onto the relative Side $H_1\Theta$ of the Rectangular Prism 007_A (the analysis is effected with the vector components of the rays on the plane of the $\Pi_1 = 013_A$ as above.

In this way, each Side $\Theta'H'_1$ and $\Theta'H'_2$ of the Curved Rectangular Prism $H'_1\Theta H'_2= 007_A$ made of for example common water clear glass (with a diffraction index n=1,5), it will present an increasing curvature in relation to the corresponding Sides ΘH_1 and ΘH_2 of the Rectangular Prism $H_1\Theta H_2$, whose angle of curvature φ_2 at the each time Point K'_1 or K'_2 of the $\Theta'H'_1$ and $\Theta'H'_2$ will be equal with great approximation with the half of the corresponding angle φ_1 at the each time points K'_1 or K'_2 of the internal Periphery Π_1 as above, while at the top Θ' we will have a rectangular intersection of the $\Theta H'_1$ and $\Theta H'_2$.

The need for the construction of parabolic or ellipsoidal or paraboloidal TRR 001_A or 201_A or $201'_A$ with curved Rectangular Prisms as above, becomes even more compulsory when it desired to employ ellipsoidal or paraboloidal Secondary Reflectors 201_A or $201'_A$ or 231_A which must transfer the Focus 204_A or 504_B behind the Primary Reflector 001_A or 101_A or 501_A shrinking or reducing the Solar Image in order to accomplish large concentration ratios (over 1500 suns). In this case the focusing must be accurate both in the Primary as well as in the Secondary Reflector, which needs also relative Curved Rectangular Prisms 007_A as above, but where the exact relationship amongst the each angle φ_2 and the corresponding angle φ_1, both in the each time Primary and the Secondary Ellipsoidal or Paraboloidal Reflector, will be

determined by a suitable Computer program depending on current needs of focusing as described above.

5. Corrected Solar Arteries and Solar-Arteries-Grid-Elements with Curved Rectangular Prisms

Another application where the construction of TRR with Curved Rectangular Prisms is needed is the manufacturing of hollow Solar Wave-Guides (Solar Arteries) with small losses or small leakage of radiation to the outside, so that transportation of Solar Radiation in great distances with acceptable losses is achieved, for example for the transportation of solar radiation inside a building for the substitution of artificial with solar lighting. The Drawing 1c shows the typical construction of a hollow Solar Wave-guide with total reflection walls (Solar Artery). The Drawing 1d shows the Detail A, which shows the implementation of Curved Rectangular Prisms that raises the optical imperfection of diffusion in a conventional Solar Artery (due to the conventional Rectangular Prisms). The Solar Artery 551_A consists of a hollow Pipe with thin Walls 554_A from transparent material with very small absorption-factor of solar radiation for example special transparent plastics or other clear materials by which are manufactured optical fibers, as the PMMA or the fused silica or even transparent glasses without iron-oxides. The internal wall of the Pipe is smooth, cylindrical with a diameter from a few centimeters (or smaller) up to tens of centimeters (or bigger). The external wall of the pipe is bas-relief and is constituted by many, parallel between them (and to the axis 553_A of the Pipe), Curved Rectangular Prisms 556_A as these are defined below.

The Walls 554_A of the Solar Arteries have their Internal Surface smooth, cylindrical, while their external surface is also cylindrical, bas-relief with parallel and at the same time Curved Rectangular Prisms 556_A, whose Acmes 557_A are parallel to the Axis 553_A of the Solar Artery and their Acmes-Angles 558_A will be 90° only in a small area near the Acmes-Angles 558_A. The external surface of the Curved Rectangular Prisms 556_A will be covered with a suitable transparent Protective Layer 562_A, as those that are used for the protection of the external surface of the optical fibers in the telecommunications and finally this will be protected by an External Plastic Mantle 563_A. The diameter of the Solar Artery 551_A will be big enough so that the focused Narrow Beam 053_A at the end of the 551_A near the focus will be inside a circle of optical angle e.g. 10°-20°, when we look at it from the Periphery 555_A of the section of the

Artery 551_A towards the Center 552_A (dependent upon the index of refraction of the transparent material of the) Artery Walls 554_A) in order to be inside the total reflection angle of the Curved Rectangular Prisms 556_A as well as the relative angle of the Solar-Arteries-Elements 571_A and 581_A equipped with Total Reflection Reflectors 571_A and 581_A as they are mentioned below.

A Beam of Rays 053_A (Beam) must enter into such a Solar Artery 551_A from its one end in such a way that the Focusing Point $504'_B$ of the Beam 053_B coincides with the Center of the Opening 552_A of the Solar Artery 551_A and the Symmetry-Axis of the Beam 053_A to coincide with the Symmetry-Axis 553_A of the Solar Artery. The Focusing Point ($504'_B$) of the Beam 053_A is actually not a point but a Circle Π_2 with a Diameter (Δ_2), where (Δ_2) < (Δ) = Diameter of the Solar Artery, that will be named Entry-Circle 560_A. In the illustrated embodiment, the diameter of the Entry-Circle 560_A of the Beam 053_A should appear from any point of the Internal Walls 555_A of the Solar Artery 551_A under an angle smaller than $2\psi*5°$ (where the factor $\psi>1$ becomes greater as long as the opening-angle of the Beam becomes smaller e.g. for an opening-angle of the Beam equal to ± 5° and index of refraction n = 1,5 the Diameter of the Entry-Circle can become equal with the Internal Diameter of the Solar Artery). The above condition is necessary in order for any Beam of Rays $053_A$to be incident onto the internal surface of any Curved Rectangular Prism 556_A with an angle smaller than $\psi*5°$ for an index of refraction n = 1,5 so that we have total reflection of the Solar Beam 053_A from any Curved Rectangular Prism 556_A found in their way.

In order to be possible to implement the requirement of incidence under angle $\pm \psi'*5°$ (where $\psi'*5°$ = the projection of $\psi*5°$ in a level vertical to the Axis 553_A) relative to the radius of the Δ_1 at any point of the internal periphery Δ_1 of the 555_A, the incoming Beam of Rays 053_A must have an Entry-Circle with Diameter $\Delta_2 < \Delta$ and an opening-angle φ smaller or equal to $\pm \psi*5°$ relative to its axis of transmission, where $0<\psi<45/9$.

The correction which is imposed by the structure of the Curved Rectangular Prisms causes a behavior in the total reflection of rays in such a way that the projection on a level Π vertical to the Axis 553_A of a ray that impinge under an angle $\varphi<\psi*5°$ on the internal walls of the Solar Artery 551_A, to emerge parallel to the projection on the Π of the ray incoming, so as to continue with sequential reflections (where the projection on the Π of each emerging ray is parallel with the corresponding projection on the Π of the incoming ray) to impinge always on

the next points of incidence on the Internal Walls 555_A with an angle that ensures the total reflection from the Curved Rectangular Prisms 556_A.

The Rays A_0K_{10} of the Beam 053_A which impinge with a lateral angle φ onto the Internal Walls (where on the projection as above e.g. $\varphi<5°$ for n=1,5), due to the lateral peculiarity of the total reflection, will emerge from their total reflection in the Curved Rectangular Prisms 556_A towards the same side from where they entered and parallel (in the vertical projection of their routing) to the incident Ray A_0K_{10}. In this way even the Rays, which impinge laterally on the Internal Walls (but always with an angle φ, e.g., $-5° < \varphi<5°$ for n =1,5) will suffer successive total reflections, where the angle of incidence on the Internal Walls will be within the limits for the achievement of total reflection, since each time it emerges parallel (related to the vertical projection of its routing) with the incident ray, which thus maintains its relative location for total reflection always passing from the interior of the Circle $\Pi_2 = (560_A)$ (something that ensures always that in the next point of contact with the Internal Wall 555_A of the Solar Artery 551_A will also have ensured Total Reflection).

On the contrary, without the corrective routing imposed by the Curved Rectangular Prisms 556_A the Emerging Ray $K_{20}\Delta_0$ from the total reflection would divert from the parallel routing to the incident Ray AK_{10}' (for the example of the Ray A_0K_1' with vertical incidence of its projection in the level Π at the Point K_1' of the Internal Wall 555_A of the Solar Artery) in each total reflection by an angle φ_1 (for n=1,5), where φ_1 is the curvature-angle at the incidence point as is defined above (the same relation will also be valid for lateral incidence as above). After a number of total reflections, and due to the algebraic summing of the error of divergences as above, the reflected ray would come out of the limits of the borderline of the Entry Circle $\Pi_1=561_A$, in which limits we have total reflection, therefore this ray in the next incidence would not undergo total reflection on the Internal Walls of the Solar Artery and would come out (loss).

Consequently, in the case of the Solar Artery the Curved Rectangular Prisms 556_A must impose a correction to the routing of the Emerging Ray $K_2'\Delta$ (with left-handed rotation of $K_2'\Delta$) by an angle φ_1 ($1x\varphi_1$ instead of $3x\varphi_1$ as in the parabolic reflectors above) in order for the projection of $K_{20}'\Delta_0$ described above to emerge parallel to the projection of incident Ray A_0K_{10}' (and the $K_2'\Delta$ parallel to the AK_1').

Therefore, the K_2K_2' should be rotated in left-handed orientation by φ_1/n (in the example with $\varphi_1 = 1°$ by $1°/1,5 = 0,6767°$), therefore the sides $H_1\Theta$ and ΘH_2 of the conventional Rectangular Prism should be turned around the points K_1 and K_2 by ($\varphi_1/4n$ each one, the $H_1\Theta$ right-handed and the ΘH_2 left-handed respectively (in the example with $\varphi_1 = 1°$ by $1°/4x1,5 = 0,1667°$). Thus, the sides of the Curved Rectangular Prisms 556_A will have at each point K_1 a curvature equal to $\varphi_1/4n$ where φ_1 the corresponding angle in each Point K_1' and n the index of refraction of the material of the Solar Artery (again it has been considered that $\sin\varphi_3/\sin\varphi_4 = \varphi_3/\varphi_4 = n = 1,5$ due to the very small angles). Actually, the correction imposed even by the Curved Rectangular Prisms 556_A for Rays that incident under a lateral angle is not 100% (that is the emerging ray is not completely parallel with the incidence ray), because differences in the required curvature depending on the removal of the total reflection points K_1, K_2 from the central locations that correspond to the reflection of the vertical to the 555_A incident ray. However, the correction that is imposed with the statistical mutual attenuation of the divergences up or down to the initial incidence-angle (dependant on if the second total reflection falls to the right or to the left from the ideal K_1 or K_2) gives the possibility to the Solar Arteries 551_A to present losses of at least one order of magnitude smaller than the conventional Solar Pipes (Solar Tubes), which use reflective walls of total reflection, but with Rectangular (and no curved corrective) prisms of total reflection. Accordingly, for the same percentage of losses, e.g., 50% the Solar Arteries 551_A will be able to transport the Solar Light at least one order of magnitude longer in a building for solar lighting, etc. (e.g., if a conventional Solar Pipe for 50% losses transports the Solar Light 50 meters, a Solar Artery with Curved Rectangular Prisms will transport it 500 meters or even more for the same level of losses).

As an alternative, in the Corrected Solar Artery $551'_A$, which is also constructed as the above-mentioned Corrected Solar Artery (551_A) (and it bears structural elements with the same numbers but highlighted with tones) but it is characterized by the fact that the corrective route, which is imposed by the Curved Rectangular Prisms (556_A) to the Emerging Ray $K_{20}\Delta_0$ from the total reflection can impose a divergence from the Incident Ray A_0K_{10}' (for the example of the vector component Ray AK_1' with vertical incidence on the level Π at the point K_1' of the Internal Wall 555_A of the Solar Artery) in each total reflection by an angle $\varphi_1/4n \leq \varphi_2 < 3\varphi_1$, e.g., for angle $\varphi_4 = 3\varphi_1$ (with n=1,5 as in the case of the parabolic and paraboloidal reflectors in Section 1 above

and as it is shown in the Drawing 1b Detail A), where φ_1 is the curvature-angle at the incidence point as it is defined above (the same relation will also be valid for lateral incidence as above) whereupon the $K_2'\Delta$ does not emerge parallel to the AK_1' but converges to the Focus E as in the case of the parabolic and paraboloidal reflectors in Section 1 above. In this case, irrespective of the Solar Artery $551'_A$, the Curved Rectangular Prisms 556_A must impose a correction on the routing of the Emerging Ray $K_2'\Delta$ (with left-handed rotation of $K_2'\Delta$) by an angle $\varphi_4=3\varphi_1$ (as in parabolic reflectors above). Therefore, the K_2K_2' should be turned left-handed by $2\varphi_1$ (in the example with $\varphi_1 = 1°$ by 2°) and thus the sides $H_1\Theta$ and ΘH_2 of the conventional Rectangular Prisms should be turned around the points K_1 and K_2 by $\varphi_1/2$ each one, the $H_1\Theta$ right-handed and the ΘH_2 left-handed respectively (in the example with $\varphi_1 = 1°$ by 0,5°). That is, the sides of the Curved Rectangular Prisms 556_A will have at each point K_1 a curvature equal to $\varphi_1/2$ where φ_1 the corresponding angle in each Point K_1' and n the index of refraction of the material of the Solar Artery (again it has been considered that $\sin\varphi_3/\sin\varphi_4 = \varphi_3/\varphi_4 = n = 1{,}5$ due to the very small angles).

The optical systems for the transportation of the visible part of the solar spectrum, which use conventional optical fibers (even high-quality fibers) for distances of the order of the 20-30 meters suffer from optical losses in the order of 50%, because it does not exist suitable material for all the wavelength range of the visible solar radiation spectrum (each material of optical fiber is tuned at a special wavelength, outside from which the optical losses increase vertically). On the contrary, all Narrow Beam of Rays 053_A that enter the Walls 554_A of the Artery 551_A internally undergo total reflection by the external Curved Rectangular Prisms (556_A) and emerge again from the internal side according to the laws of total internal reflection, as it is described below, and travel along the interior of the Artery (551_A) inside the air with minimal losses compared to the conventional optical fibers constructed from the same quality transparent material (e.g. fused silica, super clear plastic optical fibers etc). Each reflected ray in the Solar Artery 551_A after each total reflection travels in the interior 551_A at least 10-100 times bigger length in the air than in the transparent optical material (dependant on the thickness of the Walls 554_A and the Diameter 555_A of the Artery 551_A), decreasing thus its absorption losses by an equivalent factor.

Consequently, for same distances of transportation of the visible solar spectrum and the same construction material, the use of Solar Arteries 551_A will decrease the optical losses in a

small percentage 5-10% or even smaller of the above reported losses of optical fibers, allowing thus the transport of the visible part of the solar spectrum 10 or 20 (or even more) times longer for the same level of losses.

The Solar Arteries 551_A in combination with the Corner Elements 571_A and Elements of Concentration or Distribution 581_A, as described below, that allow the creation of a Collection-Network 590_A and a Distribution-Network (590_B) towards the corresponding Solar Lighting Fixtures 591_A inside a building (the Lighting Fixtures 591_A also can be provided with conventional lamps with dimmers for the compensation of the daily reduction of solar light, during the nights etc.).

The Solar Arteries 551_A are implemented preferably in straight parts for biggest exploitation of the Opening-Angle φ of the Entering Beam 053_A (they can also accept changes of the angle of their routing-axis up to the limits that are allowed by the each-time achievement of total reflection). The requirements of a big change of direction along the routing (e.g. 90°) are implemented by the Corner Element 571_A, which is constituted by the incoming and outgoing Solar Arteries 551_A (fixed and rotated around their axis) and by one conventional Reflector 574_A with high reflectivity for the Wide Beam 052_A with an angle, e.g., $-45°<\varphi<45°$ or for the Narrow Beam 053_A with an angle e.g. $-5^o<\varphi<+5^o$ a Total Reflection Reflector 575_A with parallel Rectangular Prisms 576_A, whose Top-Acmes 577_A are parallel to the level that define the axes 578_A and 579_A of the Entry Parts 572_A and Exit Parts 573_A.

The Reflector 574_A or the TRR 575_A is placed under an angle of 45° to the axis 553_A of the Solar Artery in order to change the direction of the transmitted Solar Beam 053_A by 90°, but can change the placement-angle, e.g., to 50° for the achievement of a change of the direction of the Beam 053_A by a double-angle, in this case by 100°.

The Corner Element 571_A can be also implemented with a Prism $571'_A$ of right-angle divergence made of a diffractive clear material or crystal or even water clear glass, which functions at $-90°<\varphi<90°$, imports however losses of reflection by the entrance and by the exit of the Beam 053_A. For the entrance of many Beams 053_A from various small Solar Arteries 551_A in one bigger Solar Artery, it can be used the Multiple Corner Element 581_A that has a Polygonal Reflective Surface 582_A constituted from many TRR 575_A each under an angle of 45° to the Axis 553_A of the opposite Solar Artery 551_A, and supported suitably on the perforated against the 551_A Nutshell 583_A by which 575_A the Beams 053_A from various Solar Arteries 551_A with small

diameters enter into a bigger Solar Artery 561_A, or reversely from a bigger Solar Artery $551'_A$ they come out and are distributed into many smaller Solar Arteries arranged circularly under an angle of 90° to the Axis $553'_A$ of the $551'_A$. The Multiple Corner Elements can be also materialized by the frustum-cone-shaped (internally) Prism $581'_A$ from a material as the $571'_A$, which, however, imposes an increase of the angle φ and losses of reflection of entrance-exit.

Finally, for the subtraction of Solar Radiation from a bigger Solar Artery ($551'_A$) to a smaller one (551_A), a Subtraction Corner Element $571'_A$ is used. Substraction Corner element $571'_A$ is constituted by a circular Conventional Reflector $574'_A$ or TRR $575'_A$ that it is placed under an angle of 45° inside the bigger Solar Artery $551'_A$ and sends the reflected, under a corner of 90°, Solar Beam 053_A through the lateral Circular-Opening 562_A into the smaller Solar Artery 551_A that begins with a diameter equal with the diameter of the Opening 562_A.